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Open Problems in the Operationalization of Multiple Criteria Decision Methods

A Brief Survey

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Multiple criteria decision making has been a rapidly expanding field during the last two decades. Apart from important theoretical developments, this relatively new branch of study has already given rise to an impressive number of applications. Nevertheless, in the operationalization of multiple criteria decision methods, a large number of problems may arise. In the literature, several of these problems have been signalled although many of them have not yet been solved in a satisfactory manner.

In this paper, we list a number of problems which in our opinion deserve more attention than they have received thus far.

1. Introduction

Traditional economic choice theory is usually based on a large set of assumptions regarding the state and structure of economic decision (or choice) problems. The most important assumptions are:

a) the specification of an unambiguous choice situation concerning a set of relevant alternatives.
b) the existence of a clearly identifiable and unambiguous rational decision-maker or policy-maker; in a multi-person decision framework, the role of the successive decision-makers involved can precisely be assessed either by defining an aggregate decision system or by estimating the relative power influence of the individuals or subgroups (see for instance, BLAIR [1], SAATY [18], SHAPLEY and SHUBIK [20]).
c) the objective(s) and instruments relevant for the planning problem concerned (possibly including equity considerations) are exactly known and precisely specified (including their mutual trade-offs).
d) the complex relationships between policy measures, policy objectives and exogenous variables are represented by means of a structural model; external impacts of decisions to be made may be either neglected or can be accurately assessed by means of such a systems model.
e) all relevant technical, institutional, social and economic side-conditions of the system concerned are known and can be specified in an operational way.
f) the time trajectory of all variables in a dynamic system can, in principle, be computed; when the state of a system is characterized by uncertainty (for instance, due to stochastic behaviour of variables), the distribution function of the stochastic elements is known, so that probability statements regarding the expected state of the system can be inferred.

g) the formal optimal solutions found for the choice problem at hand can be regarded as the best choice for the actual decision problem concerned, so that essentially the results of a prior and a posterior evaluation coincide.

It is clear that in decision practice several of these conditions are not met. Multiple criteria decision analysis has made an attempt to provide an answer to some of these shortcomings in traditional choice theory. For instance, the assessment of political priorities has received a great deal of attention in discrete multicriteria choice analysis, the process character of many decision problems has been represented in various interactive multiple decision methods, the rationality assumption has been critically reviewed, the uncertainty in many complex choice problems has been dealt with by means of stochastic or fuzzy multiple criteria methods, etc. (see, for instance, NIJKAMP and SPRONK [10], RIETVELD [14]).

The abovementioned reflection on operational aspects of decision theory has also led to a new attention for the psychological and sociological dimensions of complex choice problems (for instance, the micro-oriented approaches developed by Tversky). Despite path breaking and highly interesting recent contributions to the area of multiple objective decision making however, various limitations and flaws in the use of multiple objective decision models still do exist. The present paper attempts to discuss a set of open problems regarding the operationalization of multiple objective analysis. Several of the above mentioned assumptions (a)–(g) will be questioned. The following important issues will be dealt with successively: specification of objectives, inclusion and definition of instruments, design of alternatives, precision of information, assessment of priorities, multiple decision-makers, dynamics in choice problems, user orientation, and ex post evaluation.

2. Specification of Objectives

Very often, a multiple criteria decision problem is formalized in terms of a given set of objectives, each of which is to be maximized (minimized) over a given set of decision alternatives. Both the notion of *'objective'* and the notion of *'a given set of objectives'* are theoretical artefacts which should be handled with care.

The set of objectives, together with the set of policy constraints (see Section 3), is used as a tool by means of which the preferences of one (group of) individual(s) with respect to the state of a system can be expressed. The construction of a set of objectives thus involves two questions. First, whose preferences should be modelled, and second, which set of objectives can best be used to represent the preferences of a given individual? Especially in the public sector, the first question is often hard to answer. There, decision problems arise which do not only involve a sometimes considerable number of decision-makers, but also influence the interests of other individuals which should be taken account of (see VOOGD, [25]).

The preferences of an individual are not directly observable. Indirectly, inferences on the decision-maker's preferences can be made on basis of the decision-maker's value judgements with respect to different objectives or with respect to different decision alternatives, possibly translated in terms of the values of the objectives. Thus, the set of objectives is a means of expression which deserves a good deal of attention, both from decision-makers and analysts. Clearly, the formulation of the set of objectives is a problem demanding an element of creativity. Some researchers even maintain that the adequate formulation of a decision problem (of which the formulation of objectives is an important part) is much harder to achieve than a solution of the problem, once it has of a state-owned railway company having two objectives: maximize profits (or maybe more realistically: minimize losses) and maximize the attractiveness of transport by rail. If the company's instruments are denoted by $\underline{x}$, this problem is generally attacked by specifying a profit function $V_1(\underline{x})$ and an attractiviness function $V_2(\underline{x})$. The complication referred to above might mean in this example that the specification of the profit function depends on the level chosen for the attractiveness objective. For instance, we might have a profit function $V_1(\underline{x}, V_2(\underline{x}))$ which can be written as $V_1 = V_1^1(\underline{x})$ for $V_2 \leq V^*$ and $V_2 = V_1^2(\underline{x})$ for $V_2 > V^*$. It is evident that a problem, in which an objective is at the same time an instrument for the attainment of another objective, has to be dealt with carefully. Such a situation can normally be avoided if the two objectives have been defined by one and the same decision-maker (nevertheless, the decision-maker may be reluctant to redefine his problem). However, if both objectives would have been formulated by separate decision-makers, it might quite well occur that the objective of one decision-maker is (one of) the instrument(s) for the other decision-maker's objective. This case fo multiple decision-makers will be discussed in more detail in Section 6.

3. Formulation of Alternatives

Multiple criteria decision analysis usually distinguishes between discrete and continuous decision problems:

(a) in *discrete* decision problems the instruments are not divisible and the choice set consists of a finite (or a countable infinite) number of alternatives. In general, in this type of problems, each of the alternatives is explicitly described in terms of a series of attributes and/or a set of objectives.

(b) in *continuous* decision problems the instruments are divisible and the choice set consists of on infinite number of alternatives. Consequently, the set of alternatives can only be described implicitly by means of a series of instruments and a number of constraints. We note that this dichotomy is not suited to describle the mixed case in which one part of the instruments is divisible and the other part is indivisible. Unfortunately, this class of problems has received little attention.

An implicit assumption in methods designed for multiple criteria decision problems is that all alternatives generated with in the choice set are completely feasible. This assumption, however, is questionable in many cases. For example, often the choice set is defined in terms of a number of linear equalities and inequalities. Linear (in)equalities are frequently nothing more than linearized versions of non-linear relationships which only give a reliable approximation on a limited interval. When extreme alternatives are generated on the basis of the linearized constraint set, there is a possibility that these extremes are considerably far off from the real extremes. An implication is that maximum or minimum attainable values for individual objectives may be very unreliable. This is an unfavourable situation for methods in which the well-known ideal solution is used as a point of reference.

In many decision problems, constraints are included which attempt to take account of policy considerations other than those formulated in terms of the objectives. In our opinion, it is often better to consider these *'policy constraints'* explicitly as objectives rather than as rigid constraints (see for a discussion on various types of policy constraints SPRONK [21]).

In the case of discrete decision problems, alternatives may be generated by means of a model, but also by search processes in the real world (e.g., candidates for a vacancy).

alternatives may indeed depend on the method used. Obviously, one may try to resolve this problem by using an interactive method repeatedly, but it is by no means sure that decision-makers are prepared to cooperate during multiple iterations of the analysis.

4. Precision of Information

Traditional decision theory has taken for granted a metric measurement system for all variables included in a decision problem. This stringent assumption however has led to a limited relevance in decision practice, as much information in a real world choice problem is measured in a non-metric sense, for instance, ordinal rankings, nominal (dichotomous of polychotomous) data, fuzzy statements, etc. The awareness of different measurement systems has led to the distinction between *'hard'* and *'soft'* multiple criteria models (see NIJKAMP [9]).

Normally two *measurement* levels are distinguished, viz. the *qualitative* and the *quantitative* scale (see NIJKAMP et al. [12]):
The qualitative scale can be subdivided into a *nominal* scale and an *ordinal* scale:

- nominal: a classification into distinct groups (green or red, e.g.) or into distinct size classes (small impacts or large impacts, e.g.); a *binary system* also belongs to this class.
- ordinal: a ranking of events or effects in order of magnitude (for instance, 1, 2, 3, 4, ...); a difference between ordinal figures does not have any numerical meaning.

The quantitative (or ordinal) scale can be subdivided into an *interval* and *ratio* scale:

- interval: a measurement system which allows a calculation of (Euclidean) distances between figures, though the figures themselves have only a relative meaning.
- ratio: a measurement system in which figures have an absolute numerical meaning, so that they can be represented in a normal Euclidean system.

The relevance of this distinction is that in case of non-metric information, normal metric operations on such variables or on their attributes are not permitted. A first strategy may then be to attempt to specify the choice problem as accurately as possible, so that especially non-metric variables are redefined as measurable phenomena. Examples can be found in latent variables analyses, in which non-observable constructs are approximated by means of a set of measurable indicators. Alternatively, one may take for granted the qualitative nature of many aspects of complex choice problems. In that case, alternative analytical methods have to be designed. This implies that specific methods have to be used for multiple objective problems characterized by non-metric (qualitative or soft) information. Especially in case of discrete multiple criteria analysis, a wide variety of adjusted nonmetric methods has been developed. Examples are (see HINLOOPEN et al. [4]): prioritization (or eigenvalue) methods, permutation methods, ordinal concordance analysis, multidimensional scaling analysis and regime analysis. In addition, also various stochastic multiple criteria methods have been developed (see also NIJKAMP [9]).

It should be added that – despite the progress made in the treatment of non-metric data – there is still one problem left, viz. the mixed (metric-non-metric) problem. For the moment, the multidimensional scaling analysis is one of the few methods that is able to deal with the *'mixed'* multicriteria problem in a satisfactory way (see VOOGD [25]).

Lack of information may also occur, if instead of numerical statements (either metric or non-metric) fuzzy information is available (for instance, '*perhaps longer than*'). In a fuzzy context, the boundaries of the decision space are not exactly known. A fuzzy approach to decision problems requires the definition of a membership space which indicates the grades of membership of the variables or objects considered. A good operational example of fuzzy set theory to multiple objective decision-making can be found in LEUNG [6].

Especially in recent years, a considerable progress has been made in support systems (DSS), aiming at an interplay between experts and decision-makers on the basis of man-computer interactions (cf. NIJKAMP and RIETVELD [13]). Such decision support systems are also capable to include qualitative and less structured views from decision-makers. Such system do not aim at an optimal solution, but at structuring and rationalizing complex choice problems by highlighting the qualitative dimensions and impacts of the decision-maker's views. A major advantage of such systems is the direct availability of consequences of alternative options.

This new trend is essentially an outgrowth of recent developments in information systems for planning (see also NIJKAMP and RIETVELD [13]). In this context, the input side of complex decision problems (e.g., the problem definition, the assessment of data etc.) is receiving much attention. There is a growing awareness that the demands placed on highly technical and advanced decision methods tend to become lower as the quality of information systems increases.

5. Assessment of Priorities

Priorities can be formulated in many forms: by means of utility functions, desirable level, minimum requirements, lexicographic statements, etc. They may be formulated or assessed prior to multicriteria analysis, but also during multicriteria analysis as is the case with interactive methods. A major feature of multicriteria analysis is that the information available at the beginning of the procedure is incomplete or vague, so that a unique optimal solution cannot be determined (see also FINSTERBUSCH [3]).

When dealing with utility functions, there is a tendency to make use of linear ones. The obvious consequence is that the (possibly unknown) weights are applicable to all alternatives.

When a linear function is interpreted as an approximation of a nonlinear one, the assumption that the same weights vector can be applied to all feasible alternatives becomes questionable when the choice set includes very dissimilar alternatives. In that case different weights vectors for various parts of the choice set would be more appropriate, if one wants to retain linear formulations. This possibility of specifying more than one weights vector has not received much attention up to now (see also HINLOOPEN et al. [4]).

Problems arise with relative weights when they are interpreted in terms of relative importance. The expression '*criterion 1 is more important than criteria 2*' is not unambiguous. First we note that it is difficult to interpret this expression when the criteria do not have the same dimension. This expression presupposes in most cases a standardization of criteria. Since there are many ways to standardize (see e.g. VOOGD [25]), an element of arbitrariness becomes involved, since priority statements such as the one presented above are usually made independent from the choice of a particular standardization.

Another problem is that the above priority statement can be interpreted both in terms of a linear (additive) utility function, but also in terms of a multiplicative one. In the latter case, the weights concerned have to be interpreted in terms of elasticities.

We conclude that priority expressions in terms of weights are often used in a much more specific way in multicriteria choice methods than intended by the decision-maker (see RIETVELD [14]). One obvious approach to solve this possible incongruence is to check the sensitivity of the outcomes for particular interpretations of the priority statements. It is also meaningful, however, to investigate whether for other types of priority statements an incongruence between the languages of analysts and decision-makers is less probable to arise.

Another problem with priority statements which has often been recognized but not solved is that preferences may change over time depending on the evolution of the system concerned. Especially for decisions with long lasting effects this is a relevant issue.

6. Multiple Decision-Makers

A situation with multiple decision-makers may have two configurations:

a. horizontal conflicts. In that case there are two or more competing actors who try to pursue their own objectives. Examples are: a board of directors, a democratic institution, interest groups versus formally responsible agencies etc.
b. vertical conflicts. Then there is a hierarchical decision problem in which a central decision agency and decentralized decision units have to agree on a joint action. Examples of this situation are: a national government versus regional decision authorities, a central university board versus separate faculties etc.

Both (a) and (b) can formally be described as multiple objective decision problems, although there may be significant procedural differences between (a) and (b) due to different institutional settings. In addition to the pure cases (a) and (b) also mixed cases may be present.

A more interesting situation emerges if each decision unit in (a) and (b) is also confronted with a multiple objective situation. In that case a double conflict may arise, viz. between decision units and between objective functions. Especially case (b) is then more complicated, as an adjustment of traditional multi-level programming decision rules is needed. A formal mathematical exposition of these aspects is contained in NIJKAMP and RIETVELD [11].

In a certain sense, the conflicts between different decision-makers can also formally be described by means of game theory. This is also implied by various min-max strategies from multiple objective decision analysis.

The difference between game theory and multiple decision-maker choice theory can briefly be described as follows:

game theory		*multiple decision-maker choice theory*	
DM_1	DM_2	DM_1	DM_2
$\max \underline{v}_1(\underline{x}_1, \underline{x}_2)$	$\max \underline{v}_2(\underline{x}_1, \underline{x}_2)$	$\max \underline{v}_1(\underline{x})$	$\underline{v}_2(\underline{x})$
$\underline{x}_1 \in K$	$\underline{x}_2 \in K$	$\underline{x} \in K$	$\underline{x} \in K$

where DM_1 and DM_2 stand for decision-maker 1 and 2, respectively. Vectors $\underline{x}$, $\underline{x}_1$ and $\underline{x}_2$ denote the set of instruments to be used by the decision-makers, while K represents the feasible choice set. Finally, $\underline{v}_1$ and $\underline{v}_2$ stand for the objective function to be maximized by decision-maker 1 and 2, respectively (either as scalar functions in the game theoretic approach or as vector valued functions in the multiple decision-maker approach).

An interesting situation emerges if the conflicts between different decision units are so deeply rooted, that not only their relative priorities concerning various objectives differ significantly, but also their confidence in the model describing the underlying complex system. In that case, a multi-model situation may emerge. Then the only common element in a multiple objective, multiple decision-maker problem is made up by the set of variables describing the system. This implies formally for two decision-makers the following situation:

DM_1	DM_2
$\max \underline{v}_1(\underline{x})$	$\max \underline{v}_2(\underline{x})$
$\underline{x} \in K_1$	$\underline{x} \in K_2$

where K_1 and K_2 are sets of feasible solutions implied by the respective models preferred by decision-maker 1 and 2.

Such complex decision problems might be solved by means of a joint parametric variation of both the objective functions and the models describing the system concerned.

Finally, it should be added that multiple objective methods for a situation with multiple actors should not only aim at providing a context for conflict *resolution*, but should also provide detailed insight into the way conflicts have been *generated* (for instance, inertia in complex decision agencies, lack of cooperation, unequal distribution of political interests in the decision agency at hand, etc.). The latter aim also leads to the need to design adjusted methods that can explain the emergence of conflicts in a multi-actor situation (see also FINSTERBUSCH and WOLF [3]). In this respect, it is of utmost importance to have adequate insight into the key parameters that drive a complex multi-actor dynamic system. Thus the design of appropriate information systems and models that help to explain the emergence of conflicts is a very important issue in multi-objective decision analysis.

7. Dynamics of Decision Problems

Many (multiple criteria) decision problems have a far more dynamic nature than is often assumed in the formal analysis of these problems. The process of solving a decision problem may take some time and, sometimes, the decisions made have implications which reach far beyond the actual moment of decision. During the implementation the actual situation may alter, the decision-maker's image of reality may change and – not unimportant for multiple criteria decision problems – the decision-maker's preferences may change. In Section 2 it was already argued that during the process of solving decision problems, new insights may be obtained that may lead to reorientation and respecification of objectives. A general conclusion which can be drawn from the third section is that the choice set is dynamic. New alternatives may emerge, the choice set may be expanded by additional search, the effectiveness of instruments may change, etc.

Although the abovementioned remarks with respect to the dynamics of decision problems are probably not controversial at all, multiple criteria decision making theory still pays relatively little attention to these dynamic aspects, though fortunately, this attention is now rapidly growing (see for instance MOSCAROLA [7], and ROY [17]). In multiple criteria decision making, the optimality concept is less central than in single criterion decision making. This is partly because of the shift in interest to Pareto-optimality. More fundamentally, it is often argued in the literature on multiple criteria decision making that the most important aim of multiple criteria decision methods is to assist the decision-maker by clarifying his decision problem. That is, to help improve the picture of the set of decision alternatives and the relationships between alternatives and objectives, and to help structuring the process leading to the resolution of the decision problem. It should also be noted here, that not all multiple criteria decision methods produce a complete ordening of the alternatives and thus (or instead) an *'optimal'* solution.

Quite often, a partial ordening is the best that can be obtained. For example, various methods aim at finding a (set of) *'satisfying'* solutions, others aim at eliminating clearly inferior solutions, and so on.

In summary, the major contribution of multiple criteria decision methods is much less to optimization than to providing procedures for systematically investigating the set of alternatives and the preferences in decision analysis. As such, these methods get the character of learning tools and means of communication. Of course, when methods assist decision-makers in getting a better insight into their tradeoffs and/or in improving the communication between decision-makers and other participants, these methods have a positive contribution.

Nevertheless, a number of quations arise. How does one measure the effect of a given method on learning and communication? Given the large set of competing methods, which one may be expected to be the most fruitful? Does the insight which can be obtained through a given method outweigh the costs of employing that method? Is there a difference in the danger of manipulation between alternative methods?

With respect to learning procedures, SPRONK and VEENEKLAAS [21] have argued that a condition for a decision method to be considered a learning tool is that it should produce results which are non-trivial but are nevertheless explicable afterwards.

In the practice of decision-making, the dynamics of decision problems can be handled in several ways. For instance, in many real-world problems, one sees that the option of postponing the decision is well-known. The reason is that, after some time, part of the uncertainties involved may have been disappeared. A delay may be a rational decision, if the benefits of better information are higher than the costs of a delay. Another way to take account of the dynamics of decision problems is to construct a solution which is not completely fixed but which leaves some flexibility and thus the possibility to react to future events. It might be worthwhile to investigate whether, and if so how, the above mentioned (and possible other) solutions which are being used in practice as a response to the dynamics of decision problems, can also be included in multiple criteria decision methods.

8. Ex-Post Evaluation

A desirable feature of decision-making is that is it accumulative: experiences in the past should be used to improve the quality of decisions in future. It is striking to see, however, that although almost everyone will endorse this statement, so little attention is paid to ex-post evaluations in multicriteria analysis. There is a tendency to experience every decision problem as essentially unique, so that there would not be much to be gained by an inspection of earlier policies. Thus the benefits of ex-post evaluation will usually be underestimated compared with the costs involved. Further, ex-post evaluation may have dangerous effects for both analysts and decision-makers. It may lead to highlighting failures in the past.

The conditions for ex-post evaluation are most favourable when carried out by or under the responsibility of persons or agencies without particular ties with the persons or agencies which were involved. An obvious draw-back in this case is that insufficient information may be available for a thorough evaluation.

The lack of attention for ex-post considerations is quite general: it refers to all elements (impacts, preferences) of multicriteria analysis. First, the appropriateness of the model used to generate alternatives is mostly taken for granted. The validity of the model itself is usually not questioned, although the validation of many policy models is very problematic (see e.g., ISSAEV et al. [5]). Failures of policies are more often explained in terms of changing external conditions than by lack of validity of the model concerned.

Second, the formulation of the decision problem is often not reconsidered at the end of the process. Is this respect, important questions may be: Were the objectives formulated properly? Have there been missing instruments, etc.? (see also MONING [8]).

Third, a critical review of the appropriateness of the particular multicriteria method is often lacking. Several relevant questions may be asked in this respect. Was the decision-maker able and willing to participate? Was the alternative selected also implemented? If not, why? Which new issues emerged making the plan irrelevant or ineffective?

9. Conclusion

Multiple criteria decision making has been a rapidly expanding field during the last two decades. Aparts from important theoretical developments, this relatively new branch of study has already given rise to an impressive number of applications. Nevertheless, in the operationalization of multiple criteria decision methods, a large number of problems may arise. In the literature, several of these problems have been signalled although many of them have not yet been solved in a satisfactory manner. In this paper, we have listed a number of problems which in our opinion deserve more attention than they have received thusfar.

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